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FREQUENCY-DEPENDENT LIMITERS FOR FM SOUND BROADCASTING: optimisation of attack period and of delay-length in the variable-de-emphasis stage

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FREQUENCY-DEPENDENT LIMITERS FOR FM SOUND BROADCASTING: OPTIMISATION OF ATTACK PERIOD AND OF DELAY-LENGTH IN THE VARIABLE-DE-EMPHASIS STAGE

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Summary

Following earlier experimental investigations on the problem of noticeable gain changes when conventional programme limiters are used for f.m. sound transmissions, a variable-emphasis limiter arrangement was indicated as one solution. The arrangement comprised two limiter stages in cascade – the first regulating the level of the un-emphasised incoming programme-signals, and the second controlling, in a selective manner, the high-frequency input components raised above limiting level by pre-emphasis. In the original experimental equipment both stages were of a relatively complex design – each including a lumped-constant programme-signal delay network – to avoid momentary overshoot. New work and subjective tests indicate that the delay-line of the second stage may be omitted, with negligible programme impairment, provided that certain simple precautions are taken In particular, if the system demands no overshoot of any kind beyond certain limits that may set by a clipper at the output, the maximum steady-state output of the programme limiter should be set below the clipping level by a margin of 0.75 dB.

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1. Introduction

The action of a conventional limiter when used to prevent pre-emphasised high-frequency sound-signals from overmodulating an f.m. transmitter may itself give rise to a form of programme impairment. Gain variations in such a limiter affect all sound-signal components equally, and limiter action to regulate high-frequency components may cause obvious and objectionable level fluctuations of low- and medium-frequency components in the reproduced programme — an effect commonly known as 'gain-ducking' or 'limiter cutback'.

This form of impairment can be virtually removed by using a frequency-selective form of limiter and, following an investigation described in a previous report,[1] a two-stage variable-emphasis limiter arrangement has been suggested as a possible solution. This arrangement, shown in Fig. 1, comprises a flat-spectrum* non-overshoot limiter stage to control the level of the incoming un-emphasised programme components when necessary, followed by a 50 μs high-frequency pre-emphasis network and a variable-de-emphasis limiter stage to control any high-frequency programme components raised to an excessive level as a result of the pre-emphasis. The effect of the variable-de-emphasis stage is frequency selective — in the limit it simply offsets the effect of the preceding pre-emphasis — so that the action to control high-frequency signal components has relatively little effect on the lower-frequency components; as a result the impairment due to gain-ducking is much less than for a conventional limiter.

* The term 'flat-spectrum limiter' is used here to describe a limiter in which the gain, at any instant in time, is the same for all the signal components, irrespective of their frequency.

In the development of this variable-emphasis control arrangement the basic limiter used experimentally for each of the stages was of the non-overshoot variety, which was described in an earlier report.[2] Overshoot is avoided by a circuit arrangement having carefully adjusted gain-reduction characteristics, in conjunction with a matched delay network in the programme channel. This technique was developed for use on un-emphasised programme signals, and the characteristics selected as a result of the earlier work[2] are thus appropriate for the first (un-emphasised) stage of the variable-emphasis limiter arrangement. However, it was recognised that the design might not be the most economical for the second, variable-de-emphasis, stage; in fact, for reasons discussed in the following Sections, it seemed likely that the delay period in this second stage might be reduced,

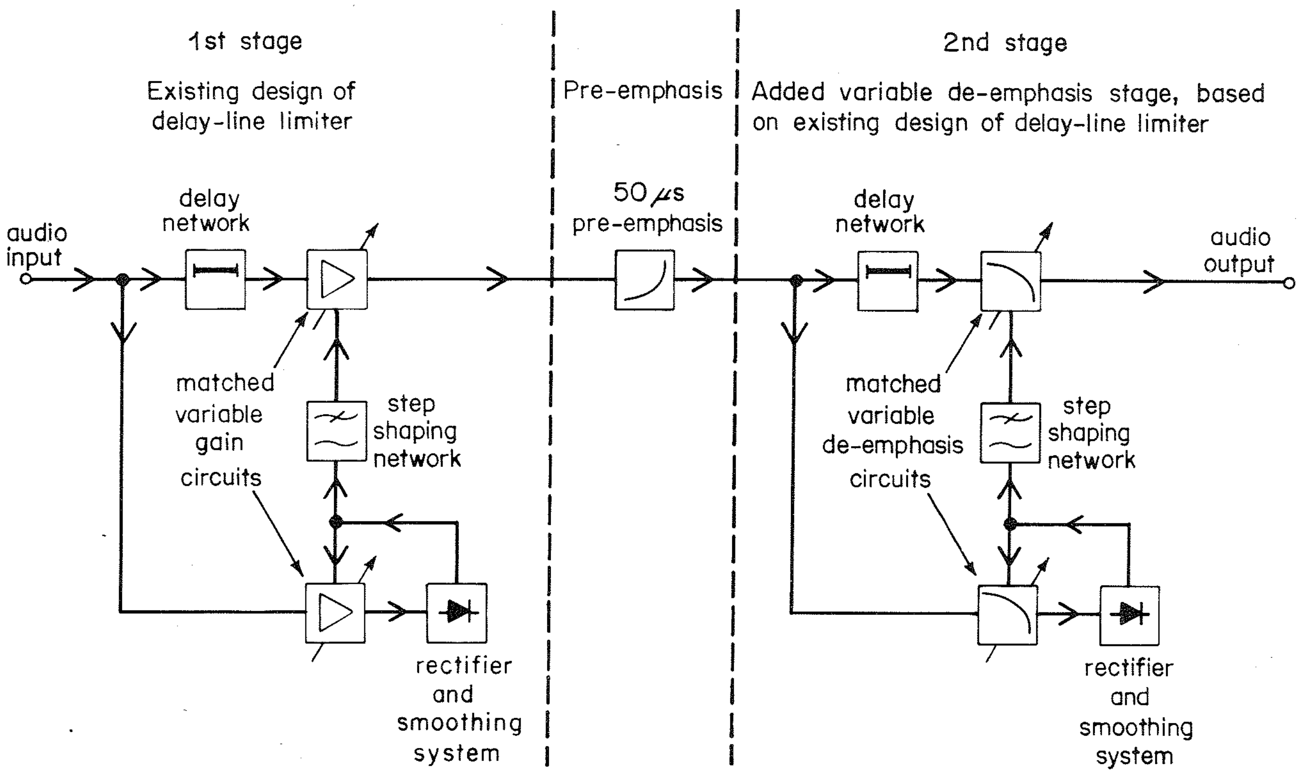

Fig. 1 - Variable-emphasis limiter arrangement: block schematic

or even eliminated entirely, without causing significant programme impairment.

Any reduction of delay period, with a corresponding reduction in cost and bulk of the delay network, would, of course be welcome, but the possibility of eliminating the second-stage delay network entirely is particularly attractive since it would lead to considerable simplification of the second stage. The feasibility of this was therefore examined in the work to be described.

2. General

The attack characteristics of the limiter stages used in the experimental variable-emphasis arrangement were based on work carried out previously in the BBC Research Department.[2] In this earlier investigation, carried out with un-emphasised programme and flat-spectrum limiters, it was established that over-rapid gain reduction could cause clicking noises or 'modulation distortion' as the limiter operated and, as a result, could impair the quality of reproduced programme. It was estimated that for the impairment to be imperceptible to all but a very small proportion of listeners, the attack period* of a delay-line, non-overshoot limiter should be not less than about 300 μs. Such an attack period, when associated with a delay line in the programme chain giving rather greater than 300 μs delay, ensured that the limiter allowed no momentary overshoot of programme signal at its output.

These characteristics, as determined for flat-spectrum limiters working on un-emphasised programme signals, are consequently appropriate for the input stage of the variable-emphasis limiter outlined in the Introduction.

The modulation distortion caused by over-rapid gain reduction comprises predominently high-frequency components. In view of this it seemed possible that, in the second stage, this distortion might be largely masked by the high-frequency signal components which alone could cause the stage to operate. Further, the action of the de-emphasis in a radio-listener's receiver would also tend to diminish the impairment due to extraneous high-frequency components. These factors both act in the direction which should tend to allow a more rapid reduction of gain to be tolerated in the second stage of the limiter than in the first stage.

An alternative approach to the simplification of the second stage is to allow momentary overshoot at its output, and then, if necessary, to restrict the amplitude of this overshoot by instantaneous clipping. This is considered further in later Sections.

*The 'attack time' of a conventional limiter is usually defined in terms of the time taken for a given reduction of the overshoot at its output when a test tone at a specified level is suddenly applied at its input. This method of specifying attack characteristic is inappropriate for a delay-line limiter where there is no overshoot; for this report therefore the term 'attack period' will be used to describe that period within which the gain reduction is completed, when referring to delay-line limiters.

3. Attack characteristics for the second stage of a variable-emphasis limiter arrangement

3.1. General

The investigation into the attack characteristics for flat-spectrum, un-emphasised limiters[2] showed that the acceptable attack period was affected by the presence or absence of the delay network in the programme channel. It was found that when there was a programme delay network in circuit — and when, consequently, gain reduction was completed before the part of the signal requiring control reached the variable-gain stage — the attack period that could be accepted, namely 300 μs as indicated above, was somewhat shorter than when there was no programme delay.

It was thought that a similar effect would prevail for a variable-de-emphasis stage; experimental arrangements for this stage, both with and without delay lines, were therefore investigated.

3.2. Parameters for a variable-de-emphasis stage having a delay line

3.2.1. Apparatus

The basic apparatus used for this test was essentially that shown in Fig. 1, with a 50 μs de-emphasis network added at the output representing normal receiver de-emphasis. Provision was made for the attack period of the second-stage limiter to be switched from nominally zero to about 300 μs, in steps of 60 μs, with similar changes to the programme-signal delay. Particular care was taken to ensure that breakthrough of the limiter control-signal into the programme channel was negligible.

Throughout the investigations described in this report the input programme level was set so that the first limiter-stage was required to exercise a maximum control of 6 dB to 8 dB, and its recovery time was set at a nominal 700 ms.* In some circumstances a longer recovery time constant, or a complex arrangement in which a longer time constant predominates,[2] may be used in this stage; the second stage would then be required to act less frequently, and impairment due to its action may be expected to be correspondingly less.

In all cases the recovery-time of the second-stage limiter was set at about 25 ms.

3.2.2. Test procedure

The subjective investigations were carried out in a listening room having a volume of some 85 metres^3 and a mid-frequency mean reverberation-time of about 0·3 secs, the programme being reproduced on a wide-range monitoring loudspeaker. Listeners carrying out this part of the investigation attended one at a time; each was allowed to

* For this report the recovery time is defined as the time taken, after an input signal causing 12 dB gain reduction is suddenly removed, for the limiter gain to increase by 8 dB.

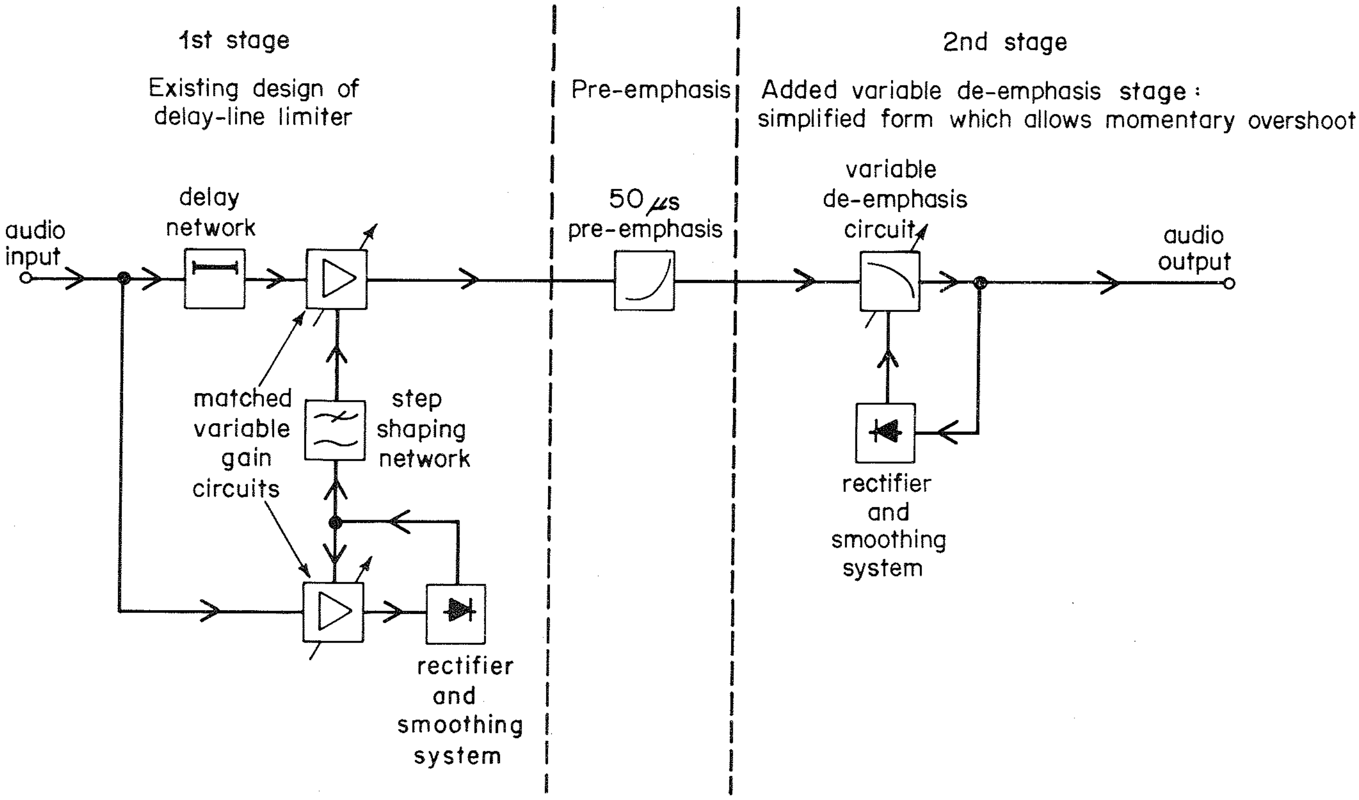

Fig. 2 - Variable-emphasis limiter arrangement with simplified second stage: block schematic

set the listening level as he wished, and was asked to adjust the attack-period and programme delay controls, ganged together, to find the minimum values for which impairment due to over-rapid control was just not perceptible. Test programme material was assessed by a few experienced listeners and, of the material presented, a passage of trumpet music was selected as the most stringent.

3.2.3. Results

It was apparent at a very early stage in this part of the investigation that, while some shortening of the attack period, and a corresponding reduction of programme-delay, might be acceptable, these could certainly not be reduced to zero without causing programme impairment. In fact, this investigation was discontinued after the tests had been carried out by three very experienced and critical listeners, who each required an attack period of not less than about 180 µs — with corresponding programme delay — if impairment due to over-rapid control was to be avoided.

In view of the greater attraction of eliminating the delay line from the second stage entirely, rather than merely reducing its length, attention was transferred to the alternative possibility of allowing momentary overshoot at the output of the second stage. The investigation included an assessment of the separation between the steady-state output limiting level and the overload point of equipment to which the limiter might feed programme (or the clipping level if protective clippers are used) necessary to avoid impairment. These tests are discussed in Section 4.

As a preliminary to this investigation some tests were carried out on the attack characteristic appropriate for a non-delay-line second stage.

3.3. Parameters for a variable-de-emphasis stage having no delay line

3.3.1. Apparatus

The apparatus used for this part of the investigation is indicated in Fig. 2. The arrangement is basically the same as that described in Section 3.2.1 but the second stage of the limiter has been considerably simplified. As a result of this simplification the limiter allows momentary overshoot by emphasised-signal components. For the purpose of the experiment a switched range of attack time was provided. The attack time of a limiter which allows momentary overshoot is defined for this report as T_{A12}, the time taken for overshoot to be reduced to 8 dB above the final steady-state level when a signal requiring 12 dB gain reduction is suddenly applied to the input. With the apparatus used the maximum rate-of-change of gain for an overshooting limiter with attack time $T_{A12} = t$ was about the same as for a delay-line limiter with attack period $2t$.

3.3.2. Test procedure

The test procedure and test conditions were the same as those described in Section 3.2.2. In this case the assessments were made by six experienced and critical listeners.

3.3.3. Results

The mean value of the attack time, for no impairment due to over-rapid gain reduction, using a non-delay-line second stage was found to be some 115 μs with a standard deviation of observations of about 27 μs. From the present data it is estimated that, for the limiter arrangement under investigation, impairment on critical programme should be imperceptible for at least 95% of the listeners, provided that the attack time T_{A12} is greater than some 160 μs. This value was in fact used for the further work described here.

4. Subjective determination of safety margin for an instantaneous clipper following a non-delay-line variable-de-emphasis stage

4.1. General

The effect of restricting by instantaneous clipping the momentary overshoot at the output of a limiter has already been investigated for a flat-spectrum limiter controlling un-emphasised signals.[2] To avoid programme impairment due to the clipping distortion it was found necessary to set the clipping level considerably above the steady-state limiting level. The precise value of this 'clipper clearance' or 'safety margin' was found to depend on the limiter parameters, but was typically more than 3 dB. It seems likely, in view of the masking of distortion by high-frequency signal components and the subsequent de-emphasis in the receiver, as discussed in previous Sections, that closer setting of an output clipper might well be acceptable for the variable-de-emphasis limiter stage. The following Sections decsribe an investigation to determine an appropriate clipper setting for these circumstances.

4.2. Apparatus

The basic apparatus required is that shown in Fig. 2, with the addition of an instantaneous peak-signal clipper after the variable-de-emphasis stage, and a differential attenuator with one section before the clipper and the other after. The differential attenuator was arranged so that the effective clipping level* could be varied in 0·5 dB steps, without altering the effective signal level applied to the monitoring loudspeaker. Again a 50 μs de-emphasis network was included in the loudspeaker circuit to represent the standard receiver de-emphasis.

The apparatus used for the investigations described in this Report comprised early prototype delay-line limiters modified to give the necessary characteristics. In these limiters the output limiting level was not entirely independent of the input programme level, and in consequence there was a slight ambiguity in the effective clipper clearance; consequently, the relevant test results for clipper clearance given here have an estimated uncertainty of ±0·25 dB.

* For this report the clipping level is taken as that level at which clipper non-linearity became visible on an oscilloscope display of the output signal versus the input signal.

4.3. Test procedure

For this part of the investigation the test procedure differed from that adopted for the tests described earlier; here the listeners attended the test sessions in groups of up to six, and for each test were asked to compare two presentations of the test item. In each presentation the test programme was passed through the variable-de-emphasis limiter arrangement; in the first presentation no clipper was included, while for the second presentation the output programme signals were passed through a clipper set at a prescribed level relative to the steady-state output limiting level of the variable-de-emphasis limiter. The listeners were asked to consider the first presentation as unimpaired and to grade the second presentation according to the 6-point impairment scale given below.

Grade	Impairment
1	Imperceptible
2	Just perceptible
3	Definitely perceptible but not disturbing
4	Somewhat objectionable
5	Definitely objectionable
6	Unusable

The tests were arranged so that the various test excerpts and the different clipper-clearance settings (for the second presentation in each test) were presented in an arbitrary order. A demonstration of the effect of severe clipping was presented to the listeners at the beginning of the test session. Preliminary tests indicated that the most critical material available comprised excerpts of solo trumpet and solo piano music, but the tests also included less critical material, comprising excerpts of sibilant male and female speech, of glockenspiel and of light orchestral music. For all the tests programme was reproduced at a maximum sound level of about 82 dBA.*

Thirteen listeners carried out the tests for all the items except the trumpet, for which results were obtained from fourteen subjects. All the listeners had considerable experience in the subjective assessment of sound-programme quality.

4.4. Test results

Fig. 3, curves (*a*) and (*b*), shows results for the tests using excerpts of trumpet and piano respectively; mean impairment grade being plotted as a function of clipper clearance. For the test conditions giving low impairment gradings the standard deviation of the observations lay in the range 0·45 dB to 0·75 dB.

With the critical trumpet and piano test passages the listeners were obviously very intolerant of conditions where waveform clipping could take place under steady-state conditions — for a clipper clearance of −0·25 dB, impairment grades of 4·2 and 3·5 respectively were obtained for

* Measured with a sound-level meter conforming to I.E.C. Publication No. 123, with 'slow' time constant.

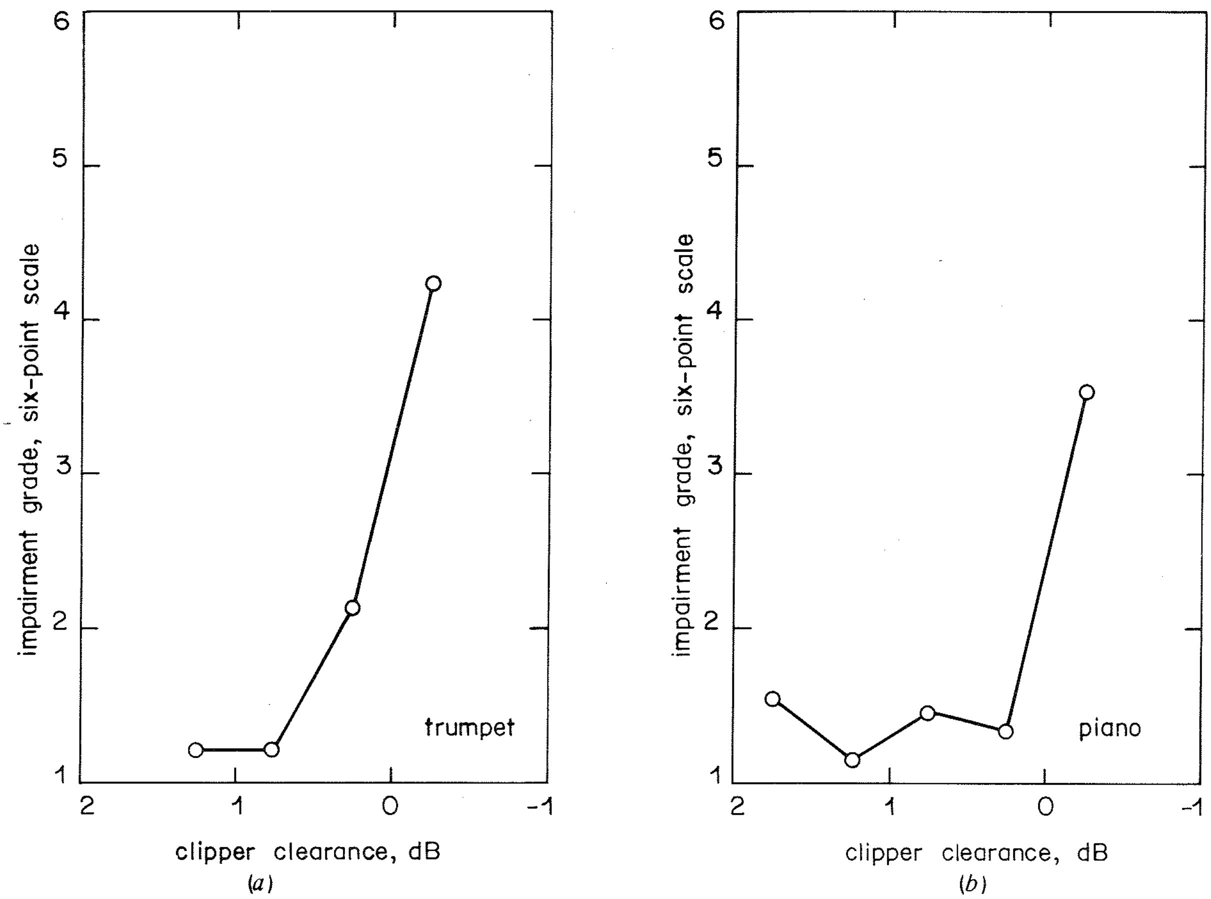

Fig. 3 - Effect of varying clipper clearance following variable-de-emphasis stage allowing momentary overshoot: mean subjective grade plotted as a function of clipper clearance

the two items. However, at a clipper clearance of about 0·75 dB the mean grade was less than 1·5.

Only a limited range of tests was carried out on the remaining, less critical items. For these the listeners were much more tolerant of overshoot clipping.

5. Provision of clipper safety margin

The clipper clearance, or safety margin, necessary after a limiter which allows overshoot, may be provided by lining up the programme-channel concerned in more than one way.

Where the apparatus to which the limiter supplies programme has a precise maximum threshold level above which serious non-linearity occurs, for example a digital transmission system, then the steady-state output limiting-level should be set down by the full safety margin of 0·75 dB to avoid significant impairment. If it is then desired to recover the effective programme level, particularly for low-level signals, this can largely be achieved by increasing the input limiter-stage gain to give a small degree of compression. Provided that the compression is no more than the requisite 0·75 dB, any impairment due to additional gain fluctuations should be entirely negligible.

When the apparatus to be protected does not have a precise threshold level, for example an f.m. modulation system, it may be acceptable to allow slight momentary overshoot. If this is the case the steady-state output limiting level may be set at the nominal threshold level of the apparatus to be protected, and peak clippers set to restrict the overshoot to about 0·75 dB above the threshold level. By this means the effective level of programme can be maintained without requiring the first limiter stage to give any compression beyond that necessary through input level peaks exceeding the nominal maximum value.

6. Conclusions

The subjective test results show that, for most applications of a two-stage variable-emphasis programme limiter, a simple second-stage having no delay line could be adopted. Where even momentary overshoots must be controlled, the clipper used for this purpose should be set with a margin not less than 0·75 dB above the maximum steady-state output level.

7. References

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